

Exhibit 13

To my children, Elana and Aaron, who have waited so patiently for me to finish this book and who are always so much fun, particularly in my class on snow days.

To my wife, Karen, whose support, encouragement, and friendship have sustained me and who has quietly done far more than her share for such a long time.

To my parents, Frances and Daniel, whose confidence and interest in whatever I do have never wavered.

And to the students of the University of Virginia, whose excitement and enthusiasm make teaching worthwhile.

How Things Work

The Physics of Everyday Life

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1.4. WHEELS

Lay down three or four round pencils, parallel to one another and a few inches apart. Rest the book on top of the pencils and give the book a push in the direction that the pencils can roll. Describe how the book now moves. What do you think has caused the difference?

Friction isn't the only force that can stop the book from moving. If you slide one book into another, the collision will slow the first book and cause the second to begin moving. To illustrate this effect, place a coin on a smooth table and flick a second, identical coin so that it slides along the table and strikes the stationary coin squarely. What happens? Now line up several identical coins so that they touch and slide another coin into one end of this line. How does the collision affect the coin that was originally moving? How does it affect the line of coins? What is transferred among the coins by the collision?

Moving a File Cabinet: Friction

When we imagined moving your friend's piano into a new apartment back in Section 1.2, we neglected a familiar force: friction. Luckily for us, your friend's piano had wheels on its legs, and wheels facilitate motion by reducing the effects of friction. We'll focus on wheels in this section. But first, to help us understand the relationship between wheels and friction, we'll look at another item that needs to be moved: a file cabinet.

The file cabinet is resting on a smooth and level hardwood floor; it's full of sheet music and weighs about 1000 N (225 pounds). Despite its large mass, you know that it should accelerate in response to a horizontal force, so you give it a gentle push toward the door. Nothing happens. Something else must be pushing on the file cabinet in just the right way to cancel your force and keep it from accelerating. Undaunted, you push harder and harder until finally, with a tremendous shove, you manage to get the file cabinet sliding across the floor. But the cabinet moves slowly even though you continue to push on it with all your might. Something else is pushing on the file cabinet, stopping it from moving.

That something else is friction, a force that opposes the relative motion of two surfaces in contact with one another. Two surfaces that are in relative motion are traveling with different velocities so that a person standing still on one surface would observe that the other surface is moving. In opposing relative motion, friction exerts forces on both surfaces in directions that tend to bring them to a single velocity.

For example, when the file cabinet slides by itself toward the left, the floor exerts on it a rightward frictional force (Fig. 1.4.1). The frictional force exerted on the file cabinet, toward the right, is in the direction opposite the file cabinet's velocity, toward the left. The file cabinet's acceleration is in the direction opposite its velocity, so the file cabinet slows down. It slides more and more slowly and eventually comes to a stop.

According to Newton's third law of motion, an equal but oppositely directed force must be exerted by the file cabinet on the floor. Forces always appear in matched pairs. Sure enough, the file cabinet does exert a leftward frictional force on the floor. However, the floor is rigidly attached to the earth, so it accelerates very little. The file cabinet does almost all the accelerating, and soon the two objects are traveling at the same velocity.

Frictional forces always oppose relative motion, but they vary in strength according to how tightly the two surfaces are pressed against one another, how slick the surfaces are, and whether or not the surfaces are actually moving relative to one another. The harder you press two surfaces together, the larger the frictional forces they experience. For example, an empty file cabinet slides more easily than a full one. Roughening the surfaces generally increases friction, while smoothing or lubricating the surfaces generally reduces it. Riding a toboggan

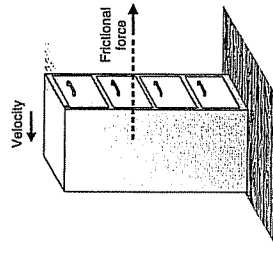
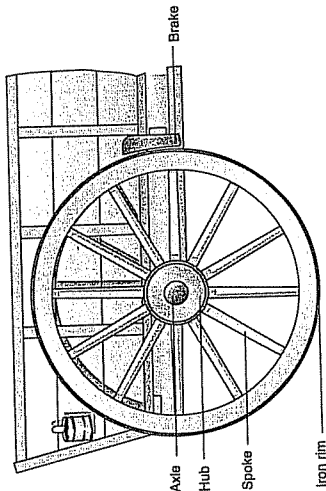


Fig. 1.4.1 - A file cabinet sliding to the left across the floor. The file cabinet experiences a frictional force toward the right that gradually brings it to a stop.



Section 1.4

Wheels

We're now almost finished with our first look at the basic laws of motion. We've explored translational motion, what initiates it, and how it proceeds; we've also examined rotational motion at some length. But we still have one more law of rotational motion to cover—Newton's third law—and we'll use another everyday object, the wheel, to explain it. Like ramps and levers, wheels are simple tools that make our lives easier. But the wheel's main purpose isn't mechanical advantage, it's overcoming friction. Up until now, we've ignored friction, looking at the laws of motion as they apply only in idealized situations. But our real world does have friction, and an object in motion tends to slow down and stop because of it. One of our first tasks in this section will therefore be to understand friction—though, for the time being, we'll continue to neglect air resistance.

Questions to Think About: If objects in motion tend to stay in motion, why is it so hard to drag a heavy box across the floor? If objects should accelerate downhill on a ramp, why doesn't a plate slide off a slightly tilted table? Why does an egg roll off that table? What makes the wheels of a cart turn as you pull the cart forward? Why do the wheels of a moving cart continue to spin for a while if you lift the cart off the ground? How does turning the wheels of an automobile propel the car forward? Why does a parked car roll forward after being struck by a moving car?

Experiments to Do: To observe the importance of wheels in eliminating friction, try sliding a book along a flat table. Give the book a push and see how quickly it slows down and stops. Which way is friction pushing on the book? Does the force that friction exerts on the book depend on how fast the book is moving? Let the book come to a stop. Is friction still pushing on the book when it's not moving? If you push gently on the stationary book, what force does friction exert on it?